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PARIS UNIVERSAL EXPOSITION, 1867.
REPORTS OF THE UNITED STATES COMMISSIONERS.

CIVIL ENGINEERING

AND

PUBLIC WORKS.

BY

WILLIAM P. BLAKE,
COMMISSIONER OF THE STATE OF CALIFORNIA.

WASHINGTON:
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CIVIL ENGINEERING AND PUBLIC WORKS.

I.—EXTENT OF THE EXHIBITION IN CLASS SIXTY-FIVE.

Class 65 of the Exposition included "Civil Engineering, Public Works, and Architecture." It is not proposed to give in these pages a full and comprehensive report upon this class. The design has been especially to notice the exhibition, by the Board of Public Works of Chicago, of the plans and details of the Chicago lake-water tunnel, of which no adequate description appears to have been given in the reports upon the Exposition. In addition, a few of the notes upon some of the other important and striking exhibitions in the same class have been written out and amplified by the aid of publications received since the close of the Exposition. Some departments of the subject have already been noticed in more or less of detail in the other reports of this series. For example, the increasing use of Coignet's agglomerated béton in construction, and the methods of paving in Paris with asphalt and with bitumen, have been carefully described in the reports made by Messrs. Leonard and Arthur Beckwith. Some observations upon the railways of France will be found in the general report, and some of the building materials are noticed in the report by Commissioner Bowen. An adequate notice of the extremely rich and varied display of materials used in the construction of great public works would alone form a volume far exceeding the limits allowed for this memorandum. Such materials include not only all varieties of stone, from granite to the ornamental marbles, but mortars, cements, artificial stones, bricks, and tiles, cast and wrought iron in various forms, zinc and other metals, wood, &c.

Very interesting and valuable reports have been made by the French and British commissions upon all these materials. One by Prof. Delesse will be found in Tome X of the Reports of the International Jury; one by Captain Ponsonby Cox, R. E., upon "Civil Engineering," in Vol. IV of the British Reports; and upon "Limes and Hydraulic Cements," by Lieutenant Colonel Scott, R. E., in the same volume. Roads and bridges, and internal navigation, foundations, and various special engineering operations have been elaborately reported upon by Baron E. Baude, of the International Jury.

EXHIBITION OF MODELS AND DRAWINGS BY FRANCE.

The most complete and comprehensive exhibition in this class was made by the minister of public works of France. It was unrivaled for its extent, interest, and value, and included models, on a large scale,

of bridges, canals, forts, docks, light-houses, &c., and was accompanied by complete drawings and explanations. Some of the most striking of these objects were the model of the great arched bridge at St. Sauveur, the Napoleon bridge in the High Pyrenees, (scale $\frac{1}{25}$), the foundations of Fort Chavagnac at Cherbourg, and the light-house de la Banche, with sections showing in detail the arrangement of the interior.

In regard to the excellence of the representations of civil engineering in the French section, and the general inadequacy of the exhibition from other countries, Captain Ponsonby Cox, R. E., observes as follows:

“Although there is no science which has given to the world such important practical results within the last few years as that of civil engineering, and though there is probably none which has made more real scientific progress, its recent progress and later results are far from being adequately represented in the Exposition of 1867.

“In the French section only is there a satisfactory exhibition in engineering proper; the other European nations, as well as the United States of America, are but slightly represented; our own country can hardly be said to be represented at all. This is much to be regretted, for undoubtedly a well-assorted collection of models or drawings of the most important engineering works scattered all over the world, which are due to the energy and skill displayed by English engineers within the last few years, would, if placed side by side with the magnificent collection of models and plans in the French section, have formed an exhibition most interesting and instructive, and would have added much to the available knowledge of the civil engineering of the world, and saved much of the labor thrown away in re-inventing. From this point of view the Paris Exposition cannot but be looked upon as a great opportunity lost. The public works of London alone might have supplied admirable examples in the great railway stations and river bridges recently constructed, as well as the works connected with the main drainage and the Thames embankment. The materials for a good display exist, no doubt, in the works of Great Britain and her colonies, but we do not possess, (nor does any other nation possess,) for tabulating these materials, such a machinery as France has in her establishment ‘des Ponts et Chaussées,’ her ‘École des Mines,’ ‘des Arts et Métiers,’ &c.”

PROGRESS SINCE 1855.

Baron Baude, member of the committee of admission of Class 65, who prepared the introduction to the class catalogue, points out among the principal technical improvements realized since 1855: 1. The progress made in the trades of hydraulic lime, cements, artificial stones, potteries, slate, and asphalts, and in that of hammered metal applied to the preservation and decoration of roofs. 2. The increase in the use of metal structures, which are more and more appreciated every day. 3. The increase in the number of machines employed in working wood

for joiners and other work. 4. The constantly increasing application of compressed air in places deep and difficult of access. 5. The ingenious methods of lifting heavy bridges, viaducts, and other metallic works. 6. The new system of movable dams. 7. The recently invented and powerful dredging apparatus. 8. The application of electricity to light-houses, and the new combinations made with a view to assist navigation, among which may be reckoned the creation of a system of coast semaphores.

PUBLIC WORKS OF SPAIN.

A very interesting exhibition of models of the principal public works of Spain was made by the Board of Direction of Public Works, and was accompanied by a memoir giving a short notice of each model and a general notice of the condition of the public works in Spain, and of the special laws and regulations under which they are executed¹. The collection contained numerous models of light-houses, models of machines and wagons used in the construction of the port of Grao de Valencia; models of the port of Tarragona; of the jetties of the port of Corogne; of the Sima aqueduct upon the canal of Isabel II; and of various bridges, reservoirs, aqueducts, and machines used in the execution of extensive public works. It was also accompanied by six volumes of photographs of the most remarkable of the public works of Spain.

II.—MATERIALS FOR CONSTRUCTION.

GRANITES, PORPHYRIES, JASPER, AND MARBLES.

Among the hard stones worked in France are the syenites, granites, and porphyries of the Vosges, the green melaphyre of Tournay, the granites and protogines of Mont Blanc. The jaspers of St. Gervais, near Mont Blanc, are attracting much attention for their beauty and novelty. The quantity is supposed to be inexhaustible, and blocks of large size are obtained. The rock is believed to result from the metamorphism of a bed of sandstone of the Triassic period.

It is banded and brecciform in structure, and presents a great variety of colors most capriciously mingled, the most conspicuous being blood-red, rose, and green. It is traversed by veins of white quartz. These beautiful jaspers were represented at the Exposition by two splendid columns at the entrance of the glass-house for the equatorial plants. Similar columns have been placed in the new opera house. The cost of the stone is 1,500 francs the cubic metre at the quarry, and 2,000 francs delivered in Paris, but it is supposed that when the quarry is fully opened the price will be reduced.

¹ Notice sur l'état des travaux publics en Espagne et sur la législation spéciale qui les régit. Traduit de l'Espagnol, Madrid, 1867.

Of marbles, France has a bountiful supply. They are obtained chiefly in the Vosges, the Alps, and Pyrenees, and from Boulogne and the Jura. Quarries at the last-named locality are regularly worked on a large scale and blocks are furnished at low prices.

The French section contained a great many beautiful marble columns designed for the new opera house. The marbles came from the quarries of Sarrancolin, (Hautes-Pyrenees,) St. Beat, (Haute-Garonne,) Félines, (Hérault,) St. Antonin, (Bouches-du Rhone,) Porcieux, (Var,) Jeumont, (Nord.)

According to the French customs returns, the exportation of French marble, which was valued at only 350,405 francs in 1855, constantly increased until the value had reached 1,140,279 francs in 1866. The importation of marble has also increased regularly during the same time, being valued at 1,038,271 francs in 1855, and at 2,357,115 francs in 1866. The disposition to use marble in construction is increasing in France.

The following figures show the prices in francs per cubic metre of the marbles most in use in France during 1867. These figures and the preceding relating to the marble industry of France are compiled from the report of Prof. Delesse:

Sarrancolin.....	1, 012
Campan mélangé and Campan vert.....	1, 232
Rosé clair	792
Griotte d'Italie.....	1, 012
Griotte œil de perdrix.....	1, 117
Languedoc.....	792
Brèche impériale	682
Vert de Maurin, (serpentine).....	1, 122
Brocatelle jaune, violette ou jaune fleurie.....	847
Sarrancolin de l'ouest.....	572
Henriette.....	627
Noir française.....	374

The display of marbles from Italy was peculiarly fine, remarkable alike for the beauty of the material and for the liberality and taste displayed in the selection of the specimens. They were in blocks a foot square and beautifully polished. The Institute Technico de Firenze also sent a splendid series of specimens of all varieties of the Italian building stones, among them a series of sixty polished blocks of serpentine of as many different shades and colors.

From Algeria there was a fine collection of some four hundred specimens, in cubes measuring six inches on a side, of the building stones of that country. These were collected by the "Service du genie militaire : des ponts et chaussées." The series contained a great variety of marbles, among them the beautiful light-colored "onyx marble," so-called, now much prized and used for interior decoration in France.

CIVIL ENGINEERING.

Belgium is extremely rich in marble of various colors, particularly the much esteemed black marbles. They are obtained in the provinces of Namur, Liege, and of Hainaut. Of the black marbles those of Denée and of Furnaux are much exported to France, Germany, and Italy. The fine black marble of Golzennes is nearly all sent to Paris. The black marble from the quarries of Peruwelz and of Basècles (Hainaut) is very solid, and is exported in considerable quantities to all parts of Europe and to America.

There are ninety marble quarries in the province of Namur; they employ nearly eight hundred and six men, and the value of the annual production is estimated at eight hundred and sixty thousand francs. The quarries of Wellin yield nearly four hundred cubic metres of marble annually, of a value of forty thousand francs. It is estimated that not less than three million francs of capital is invested in the marble industry of the province of Namur alone.

But Belgium is rich in quarries of all kinds of building stones, not only marbles, but granite, paving stones, sandstone, slates, &c., as will be seen from the annexed tabular statement of the number of quarries and value of their products in the year 1864.¹

Production of stone for the purposes of construction in Belgium, in 1864.

Provinces.	No. of quarries.	No. of workmen.	Value of the products.
			<i>Francs.</i>
Hainaut.....	463	10, 419	13, 445, 940
Namur.....	763	4, 020	4, 424, 897
Liege.....	280	2, 248	1, 868, 670
Brabant.....	139	1, 893	1, 933, 200
Luxembourg.....	106	1, 328	1, 085, 897
Limbourg.....	13	51	11, 875
Totals.....	1, 764	19, 959	22, 770, 479

The marbles of Algeria were well represented at the Exposition, particularly the “marble onyx” from quarries worked formerly by the Romans. It is beautifully veined in parallel layers like onyx, and appears to be of stalagmitic origin. It resembles the Mexican stalagmitic marble. Fine specimens of onyx marble were shown also in the Russian section.

From Scotland and from Cornwall there were several very finely wrought specimens of granite, and from Sweden a fine display of the porphyry of Elfdalen. In the Bavarian section there were two fine vases of a green dioritic porphyry.

The following table shows the weight per cubic metre of some of the various stones employed in the construction of the new Grand Opera House of Paris, and the pressure per square centimetre which each will sustain before crushing.

¹ From the Catalogue des produits industriels et des œuvres d'art, section Belgique.

Weight and strength of some of the varieties of stones used in the construction of the Grand Opera House.

Description of stone and locality.	Weight.	Crushing Weight.
Jasper of Mont Blanc, St. Gervais.....	2, 716	1, 839
Brown granitoid porphyry, Bazoches.....	2, 585	1, 487
Green porphyry, (melaphyre).....	2, 855	1, 111
Red granitoid porphyry, Autun.....	2, 585	1, 080
Porphyroidal granite, St. Martin du Puy.....	2, 567	1, 077
Micaceous granite, Lormes.....	2, 694	1, 077
Red syenite, Servance.....	2, 654	901
Syenite, ("feuille-morte,") Servance.....	2, 683	867
Porphyroidal granite, Servance.....	2, 643	715
Marble, ("sanguin,") Sampans, Jura.....	2, 637	1, 076
Marble, (violacé).....	2, 663	994
Pierre de Damparis, Jura.....	2, 683	898
Pierre de l'Echaillon, Commune de Rivière.....	2, 726	852
White Echaillon, St. Quentin.....	2, 529	781
Yellow Echaillon, Lignet.....	2, 686	777
Rose-colored Echaillon.....	2, 472	606
Pierre de Anstrude, Yonne.....	2, 261	365
Soft stone, Yonne.....	2, 161	369
Pierre de Ravières.....	2, 157	377
Grès bizarre, Lutzelbourg.....	2, 130	215

CEMENTS AND ARTIFICIAL STONES.

Cements were exhibited in great variety from France and Belgium, not only in the crude and commercial state, but worked up into various objects and molded into blocks of a form suited for testing by pressure and weighting.

One of the most interesting displays was made by the French Cement Company of Boulogne-sur-Mer, which received a gold medal. An apparatus for testing the strength of cements was included in their exhibition. Blocks of the hardened cement, about eight inches long and shaped like a stout letter **I**, were placed between strong iron clamps, and made to form a link in the chain by which a heavy platform was suspended. Upon this platform below, heavy weights were piled nearly to the limit of the strength of the slender neck of the cement block. One of these blocks, formed of four volumes of sand and one of cement, and one and a half inch square, sustained a strain of nine hundred kilogrammes. Another one, four inches square, composed of two volumes of sand and one volume of cement, sustained a weight of twelve hundred kilogrammes. The sand used in these experimental blocks was very coarse, nearly as large as beans or peas. Another method of showing the strength of their cement was by building a column of brick-work about six feet long, extended horizontally like an arm, and supported at one end only.

This cement is artificially prepared by mixing intimately and with great care $79\frac{1}{2}$ per cent. of carbonate of lime, in powder, with $20\frac{1}{2}$ of clay, and then burning at a high temperature. There are now many establish-

ments in France, Prussia, Germany, Austria, and Russia, where enormous quantities of excellent cement are manufactured. In one of the establishments recently started in France, at Pouilly, the method consists in crushing together two kinds of argillaceous limestone from the Lias; one containing 43.5 per cent. of lime, the other a belemnitic limestone, which contains 48 per cent. of lime. The first gives the cement known as the Pouilly, and the intimate mixture of the two gives a cement with the composition of the Portland cement. An analysis of this cement gives the following result:

Lime.....	62.00
Silica.....	23.00
Alumina.....	8.50
Oxide of iron.....	5.50
Water and carbonic acid.....	1.00
Sulphate of lime.....	traces.

M. Delesse gives the results of some recent analyses of Portland cement by Dr. Zuirek, of Berlin, as follows; three samples came from the principal works for the manufacture in England, and the fourth from the establishment of the Brothers Menkow, at Schwerin:

Analyses of four samples of Portland cement.

	Robins.	White Bros.	Knight, Bevans & Sturge.	Menkow.
Silica.....	22.74	22.59	22.30	24.01
Alumina.....	7.74	6.43	3.31	5.73
Oxide of iron.....	3.70	4.03	9.75	2.39
Lime.....	56.68 } 92.08	57.87 } 92.56	58.17 } 95.02	63.77 } 97.68
Magnesia.....	0.57	0.55	0.91	0.96
Potash.....	0.46	0.74	0.41	0.49
Soda.....	0.19	0.35	0.17	0.33
Sulphate of lime.....	1.66	2.67	1.17	0.24
Carbonate of lime.....	3.50	0.84	1.34	0.67
Insoluble residue.....	0.50 } 7.59	0.77 } 6.51	1.06 } 5.02	0.93 } 2.11
Hygrometric moisture.....	1.90	2.23	1.47	0.27

The Vicat cement is much more used in France now than formerly. It is manufactured on a large scale by Mr. Joseph Vicat, a graduate of the École Polytechnique, and the son of the celebrated engineer. He forms a paste with clay and slaked lime in powder. This is made into loaves, which soon set and harden so that they are not injured by the weather, and do not require housing or artificial drying, as is the case when unburned materials are used. These loaves are then burned. This is substantially the process invented by his father. M. Delesse observes of the qualities of this cement, that it is homogeneous, the elements being in perfect combination; the clay is changed into silicate, which is completely decomposed without residue in a dilute acid. The setting is slow and does not commence for several hours after the mixing as mortar. The weight of this cement pulverized, but not com-

pacted by ramming, varies from thirteen to fourteen hundred kilogrammes to the cubic metre.

Some interesting applications of this cement were shown. It is used for making artificial breccias by mixing it with fragments of marble of various colors, molding it into the desired form, and then by grinding and polishing the surface a beautiful mosaic is produced. Blocks so made may be sawed into slabs and polished like marble. They are hard and non-absorbent of moisture, and are said to be suitable for exterior decoration.

Among the hydraulic limes, that of Theil, Ardèche, continues to hold its high rank. The limestone beds from which it is obtained are highly fossiliferous, and are over three hundred feet thick. Simple burning is all that is required to produce the cement. An establishment for its manufacture at Lafarge has thirty-four furnaces and produces three hundred and forty tons of sifted lime daily. The price is fifteen francs per ton, and it weighs seven hundred kilogrammes per cubic metre. It is particularly valuable for marine constructions, and can be wetted with either fresh or salt water. It was used for the formation of the artificial blocks sunk to form the breakwater piers at Port Said.

The agglomerated béton of Mr. Coignet was most fully represented at the Exposition, and was used in the construction of the reservoirs and for the foundations of the outer gallery. For a full description of this material, its preparation and uses, reference is made to the special report by Mr. Leonard F. Beckwith. Reference may also be made to the publication by M. Coignet¹ and by M. Claudel.²

OXYCHLORIDE OF MAGNESIUM CEMENT.

By mixing magnesia with oxychloride of magnesium a cement is formed analogous to that made with zinc oxide and the oxychloride of zinc. Both of these cements are the invention of Mr. Sorel. The hardness of the cement varies with the density of the chloride solution. An increased hardness is given by saturating the chloride of magnesium with chloride of barium or with sulphate of magnesia. The addition of one part of quicklime, or two parts of carbonate of magnesia, in one hundred of the chloride at 25° Baume, augments the hydraulic properties.

FERRUGINOUS CEMENT.

M. Alfred Chenot proposes to form a ferruginous cement by mixing iron in a state of extreme subdivision with sand. A cement so formed has long been known and used to a certain extent in the United States. M. Chenot proposes to manufacture the iron in a state of division and upon a large scale, by reducing iron ore, mixed with carbon, in a close furnace.

¹ Emploi des bétons agglomérés, etc., par François Coignet, Paris, 1862.

² Pratique de l'art de construire, Paris, 1863.

RANSOME ARTIFICIAL STONE.

This remarkable compound is adapted not only to interior, but, to exterior construction, and rivals the natural sandstones in hardness and durability.

It is formed by mixing sand with soluble silicate of soda, and, when molded into the desired form, treating the mass with a solution of chloride of calcium. A double decomposition takes place, hydro-silicate of lime is formed, and binds the grains of sand strongly together. For a full description of this artificial stone and its applications, reference is made to the report by Commissioner Barnard upon the Industrial Arts.

ZINC FOR CONSTRUCTION.

Zinc in its various forms of sheets, wire, nails, and stamped ornaments appears to be much more used in construction in Europe than in the United States. The display by the Vieille-Montagne Company, and the Silesian Zinc Company of Breslau, was very extensive. Some of the advantages claimed for this material over other materials for roofing are its lightness, tenacity, and cheapness compared with lead, slates, or tiles. The Vieille-Montagne Company claim that the inclination of zinc roofs need not exceed 0^m.1 per metre, while slate requires 0^m.3, and tile 0^m.45.

For a building 12^m.50 long by 6^m.80, covered with No. 14 zinc, at 80 francs the 100 kilogrammes, the cost would be :

	Francs.
With zinc, 1,075.09 francs, or per square metre.....	13. 45
With slates, 1,245.97 francs, or per square metre.....	15. 60
With tiles, 1,745.96 francs, or per square metre.....	21. 80

For a shed 63^m.00 long, 18^m.00 wide, with an iron frame, and covered with No. 14 corrugated zinc, at 80 francs per 100 kilogrammes, the cost would be :

	Francs.
With zinc, 18,749 francs, or per square metre.....	16. 50
With tiles, 22,767 francs, or per square metre.....	20. 10

For temporary constructions they advertise sheets Nos. 10 and 11, which weigh 3^k.45 to 4^k.15 per square metre. It does not require painting, and the old sheets may be sold for thirty-five to forty per cent. of the cost of new.

The Silesian Zinc Company manufacture zinc sheets of all sizes and thicknesses, from two ounces per square foot upward. The large plate exhibited is seventeen feet long by fifty-four inches wide, and three-quarters of an inch thick. It could have been made twice as long as this, and with a total weight of forty-two hundred pounds, if room could have been procured for its installation. The corrugated sheets of large curve when laid lengthwise are made nine feet long and up to forty-one inches in breadth. These sheets are used chiefly for roofing large railway stations or other large buildings. The new exchange at Berlin is covered with zinc from this establishment. Annexed is a table of the sizes and weight of zinc sheets, in avoirdupois pounds and fractions, which may be serviceable to constructors and engineers.

MR. HEWITT ON THE USE OF STEEL FOR RAILS.

The manufacture of steel rails for railways has been discussed by Commissioner Hewitt in his report upon iron and steel, and some observations upon the form of rails will be found in the report by Commissioner Auchincloss. Since the publication of the report of Mr. Hewitt the writer has received from him the following letter, dated New York, October 20, 1869, giving the result of later investigations abroad:

“Having made a visit to Europe during the past summer, with Mr. John Fritz, manager of the Bethlehem Iron Works, at Bethlehem, Pennsylvania, for the purpose, mainly, of acquiring information in regard to the use of steel for rails, I do not think that I can render a more acceptable service to the railroad interests of the United States than by adding to my report a brief statement of the conclusions at which we arrived.

“First. It appears to be certain that on all roads doing a large business, and especially where heavy engines are run at a high speed, *steel* must be substituted for *iron*, on the *wearing surface* of the track. The steel may be either puddled, or made by the Siemens-Martin, Bessemer, or crucible process; but, whatever kind of steel may be employed, care must be taken that the steel be of good quality, and adapted to the purpose. This demands skill in the *manufacture* and care in the *inspection*. Unless the skill is used, and care exercised, there will soon be the same complaint in regard to the quality of steel as has existed in regard to the quality of iron.

“Second. For roads having a small traffic, iron rails are, as yet, more economical, provided light engines and moderate speed are employed. If proper care is used in the manufacture and inspection, and a price paid sufficient to cover the cost of good materials and workmanship, there is no more difficulty now than there was in former years in procuring iron rails of good quality. The real cause of the inferiority of modern rails appears to be due solely to the unwillingness of railroad managers to pay a price adequate to meet the actual cost of good iron and skillful work.

“Third. The question as to whether all steel rails, or iron rails with steel heads, should be used, is mainly one of first cost. There have been slight objections to steel-topped rails, when cast steel is used for the head, arising out of the liability of the steel to separate from the iron; but this objection is now removed, both in Europe and in this country, by the experience which has been gained at Dowlais, in Wales, and at Trenton, in New Jersey, and it is safe to affirm that steel and iron can be certainly united so as not to separate in the weld. The experience with the Booth rail, on the New York Central railroad, also goes to show that it is not necessary to weld the steel and the iron at all, leaving it merely a question of prime cost as to whether the heads shall be welded or not. As to all steel rails, whether made from Bessemer, Siem-

ens-Martin, or crucible steel, the only objection appears to be in their liability to break in very cold weather, but the percentage of such accidents is very small; and, all things considered, it is difficult to decide whether this objection is of more weight than the possibility of a separation of the steel from the iron in the steel-topped rails. On the whole, we came to the conclusion that we would take either the *all-steel* or the *steel-topped* rails, properly made, giving the preference to the one which could be supplied at the lowest price per ton. In other words, we believe that the question of first cost should alone decide whether to use steel-topped rails or rails made entirely from steel, provided the quality of the materials used and the workmanship are equally good in both cases.

"The Siemens-Martin process has solved the only difficulty which existed in regard to steel rails when worn out, by working them over as the raw material for new rails. This process is now in operation at most of the leading works in Europe, and can be seen at work at Trenton, New Jersey, producing steel which welds perfectly to iron, and therefore admirably adapted for steel tops."

III.—LAKE TUNNEL AND WATER-WORKS, CHICAGO.

THE SUPPLY OF WATER TO CHICAGO.

The Board of Public Works of the city of Chicago sent elaborate drawings, upon a large scale, of the tunnel and accessory constructions which were then nearly completed, for the supply of the city with pure water.

The source of the supply is Lake Michigan, from which the water is pumped by steam-engines and distributed in pipes in the usual manner. During the year ending March 31, 1867, the quantity pumped was 3,168,760,609 gallons, being an increase of nearly 391,000,000 gallons over the quantity pumped during the previous year. This gives a daily average of 8,681,536 gallons. The quantity of coal consumed in pumping was $3,761\frac{710}{2000}$ tons, and the expenses, including salaries and repairs, amounted to \$44,452 14, or \$14 03 per million of gallons.

Before the construction of the lake tunnel about to be described, this water was drawn from an inlet-basin, upon the margin of the lake. During the severity of winter quantities of ice accumulate across the entrance of this inlet-basin, forming a ridge or barrier, so as to cut off effectually the supply of water from the lake, and thus necessitating the exertions of gangs of men day and night to keep a passage open to the pump-well. This difficulty, and the constantly increasing numbers of small fish, and the fouling of the water along the shores by the sewage of the city, and deposits of small streams, led the citizens to the project of obtaining the water from a point so far out in the lake as to be beyond these local annoyances. But before the final adoption of the plan of a tunnel, to extend two miles under the bed of the lake, some

five or more different methods of securing the pure water were more or less considered. These were—

1. The extension of the old inlet pipe a mile out into the lake, at an estimated cost of from \$66,000 to \$125,000 for the iron pipe alone.

2. A brick tunnel, six feet in diameter, and extending a mile out into the lake.

3. Removal of the pumping works to Winetka, about sixteen miles north of the city, and conducting the water to the city in pipes from a reservoir placed upon the high ground at Winetka.

4. Filter beds, at an estimated cost of \$107,500.

5. A subsiding reservoir, at an estimated cost of \$107,775.

THE LAKE TUNNEL.

The plan of tunneling two miles under the bed of the lake was proposed by E. S. Chesbrough, esq., the city engineer, and was executed under his superintendence. It is one of the most novel, successful, and economically executed engineering enterprises of the present time, and justifies a notice in considerable detail.

The notice which follows has been freely compiled from the information given in the annual reports of the Board of Public Works of the city of Chicago to the common council, and from the manuscript notes and explanations supplied by Mr. Chesbrough, at the request of the writer. The two lithographic plates, also, which illustrate the description, are engraved from photographic reductions of the large drawings which were displayed at the Exposition.

The plan of tunneling was adopted by the board of public works as early as 1863. During that summer examinations were made along the whole line of the contemplated work by boring, at short intervals, to the depth proposed for the tunnel, to ascertain the character of the material through which it would pass, and various observations were made to test the quality of the water at the proposed outer end and inlet for the tunnel, and to ascertain also the distance from the shore to which the water of the river reached after certain most marked discharges of the river into the lake. From the borings it was found that the material through which the tunnel would be built was uniformly clay, and apparently of a firm and even character; and the observations concerning the effect of the river on the lake showed that, even when most marked, no trace of its influence could be detected much more than a mile and a quarter from the shore. The information obtained on these and various other points satisfied the board that the tunnel would accomplish the results sought for, and that the work was entirely practicable. The necessary drawings and specifications were prepared as speedily as practicable, and advertisements were issued in New York and Boston, as well as in Chicago, inviting proposals for the doing of the work. The bids were received and opened September 9, 1863, most of the parties submitting proposals being present at the opening.

The following record describes particularly the bids received for constructing the tunnel complete:

Bids received for the lake tunnel September 9, 1863.

Name of bidder.	Lake tunnel complete.	Lake tunnel and land shaft alone, in case there should be two lake shafts.	Lake tunnel and land shaft alone, in case there should be three lake shafts.	Lake tunnel and land shaft alone, in case there should be four lake shafts.
James Andrews, Pittsburg, Pennsylvania	\$239, 548	\$151, 987	\$148, 000	\$144, 000
James J. Dull and James Gowen, Harrisburg, Pennsylvania	315, 139			
Stephen C. Walker, Asa D. Wood, and F. W. Robinson, New York	*315, 000			
Thomas Williams, John McBean, A. S. Brown, and George Neilson, Chicago	†490, 000			
Hervey Nash, Chicago	‡40			
D. L. DeGolyer, Chicago	§620, 000	410, 000	400, 000	¶380, 000
William Baldwin, New York	1, 056, 000			

* " Meaning to include but one intermediate lake shaft. This proposal is based upon the supposition that the material to be excavated is firm, and such that the tunnel can be made and the masonry built without the use of permanent bracing. But if in the prosecution of the work, to secure its safety, permanent bracing should be required, the attendant increased expenses shall be paid by the city. The chief engineer to decide the amount."

† " For all the work except the iron cylinders for shafts. In case sand or gravel veins occur, to be paid for extra. This sum includes four cribs."

‡ Per lineal foot.

§ " I run the risk of all loose earth, sand, or gravel."

|| " \$100 per lineal foot, if material is 'stiff blue clay soil.' If otherwise, extra pay and extra time will be required."

¶ " 360,000 ?"

The bid of Messrs. Dull and Gowen, of Harrisburg, Pennsylvania, being unconditional, and for the whole work, it was accepted as the lowest and best bid, and the contract, which will be found embodied in this notice beyond, was drawn up. Subsequently to the execution of the contract the board decided to change the manner of constructing the land shaft, which was originally designed to be wholly of brick. This change consisted in substituting three cast-iron cylinders, each ten feet long, essentially like the iron cylinders proposed for the outer lake shaft, in place of the brick-work of the upper thirty feet of the shaft. This was done to facilitate the sinking of the shaft through the bed of quicksand overlying the clay, the distance through the quicksand to the clay being about twenty-four feet.

In place of a description in detail of the construction of the tunnel, the contract and specifications are given in full, particularly as the work is minutely described, and as the contract shows not only what was at first required of the contractors, but, together with the notes and explanations, shows also the changes which it was found desirable to make during the progress of the work.

LAKE TUNNEL CONTRACT.

LOCATION AND GENERAL DESCRIPTION.—The tunnel is to commence at such point as may be selected by the board of public works, on the lot now occupied by the pumping works of the city of Chicago, at the east end of Chicago avenue, and on the shore of Lake Michigan; and to extend two miles out under the lake, in a straight line, at right angles to the general direction of the shore.

The bottom of the inside surface of the east end of the tunnel shall be sixty-six feet below the ordinary level of the lake, or sixty-four feet below what is usually known as "City Datum;" and the bottom surface shall descend uniformly at the rate of two feet per mile to the west end of the tunnel.

There are to be one land and two to four lake shafts; the land shaft at the west end, one lake shaft at the east end, and the remaining lake shaft or shafts at such intermediate points as shall be determined upon by said board, when the proper time for locating them shall arrive. The lake shafts are to consist of cast iron cylinders, and to be protected by hollow pentagonal cribs.¹

The tunnel is to be very nearly circular in form, and to have an interior width of five feet, and height of five feet and two inches.

CRIBS.—It has been proposed to construct four cribs, on the supposition that this number might be required to complete the tunnel in two years, but if, after commencing the work, it shall be found in time that one or more of them may be omitted, such omission shall be made; and for this reason but two cribs² shall be commenced before the probable rate of progress in the tunnel, from the land shaft, shall have been satisfactorily ascertained.

DESCRIPTION.—The cribs are to be five-sided, each outer side to be fifty-eight feet long. There is to be a central space in each crib, in form similar to the outside, leaving the thickness between the central space and outside of the crib twenty-five feet. The interior and exterior sides of the cribs are to be perpendicular from their bottoms to their tops, which are to be five feet above the ordinary surface of the lake; hence the outermost crib is to be forty feet high. The height of the others will depend upon their location, which will be determined during the progress of the work.

The outer crib is to have three openings through its sides, one opening through each of the western and southern sides; each opening to be five feet high and four feet wide, and to be connected with the top of the crib by a well four feet square. The most northern opening is to have its bottom five feet above the bottom of the crib, the middle one eleven feet higher, and the southern one eleven feet higher than the middle. Each opening is to be furnished with an iron paddle gate, to be worked by means of an iron rod, from the top of the crib, as shown on plans.

¹ Only one lake shaft and one crib were constructed.

² Only one crib, the outer one, was found necessary.

Each crib is to be provided with two gates,¹ each two feet high, and one and a half foot wide, placed five feet above the bottom of the crib, and against the wall of the inside space. These gates to be used for regulating the sinking of the cribs to their places, and worked by rods from the top of the crib, as shown on plans. Wrought-iron gratings to protect these gates must be provided, as shown on these plans.

MODE OF CONSTRUCTION.—The bottom of each crib shall be formed by an outer, inner, and middle line of twelve-inch square white pine timber, which shall be connected with cross-timbers of the same size, and with twelve-by-three-inch joists placed two feet apart from center to center, and the under side of the whole, except the central space of the crib, sheathed over with two-inch pine plank, fastened on by six-inch spikes, driven through each plank in every timber and joist, as shown on plan.² All the timbers and cross-timbers are to be connected by dovetail joints the full width of each timber, and of equal depth in each, the dovetail being one inch deeper at its end than at its shoulder. On the outer, inner, and middle lines of timber, and on the angle pieces of the outer and middle lines, solid walls of twelve-inch square timber are to be built up to a height of forty feet above the bottom for the outer crib, and to a height of five feet above ordinary water-mark for the other cribs. The middle wall extends solid from outside to outside of the crib; the inner wall only around the inner space. The angle timbers are eleven and a half feet long from tip to tip. Between the outer and middle walls there are two lines of cross-timbers on each side of the crib, and between the middle and inner walls three lines.³ The cross-timbers are twelve inches square, placed twelve inches apart above each other, and extend through each wall. All of the timber and lumber, except the upper twelve feet in each outside wall, is to be of sound white pine. The upper twelve feet of the outer wall to be of sound white oak, free from sap, or any imperfections tending to hasten decay. All of the joints of the timbers at the angles of the outer and inner walls, at the ends of the middle walls, and at the ends of the cross-timbers, are to be dovetailed like those described for the bottom course of timbers in the crib, [at the corners.] Where the timbers of the middle wall cross each other, they are to be notched half and half. Whenever the ends of timbers butt against each other in the outer and inner walls, they must do so at the center of the end of some cross-timber, where the dovetailed end can be made to lap over the butt joint. On the bottoms and sides of the three openings through the outer crib, twelve-inch square timbers touching each other are to be run entirely through the ends; and across the

¹ This was afterward changed, and eight smaller and circular gates were constructed so as to regulate the flow of the water into eight water-tight compartments, which occupy the interior of the crib.

² Changed in construction to twelve-inch timbers.

³ In construction, these timbers were placed so that each piece extended from the outer through the middle to the inner wall.

top of the openings six-inch planks are to be spiked, fitting close to each other. The walls from each opening to the top of the crib are to be formed of six-inch planks placed horizontally, and notched into the crib timbers wherever they can be.

The timbers in the outer and middle walls of each crib are to be fastened to each other by $1\frac{5}{16}$ -inch square wrought-iron bolts thirty inches long, with ragged edges, and driven into the timber at an angle twelve degrees from a perpendicular, and inclining alternately toward each other. [The ragging was omitted.] The timbers of the inner wall are to be fastened in a similar manner to those of the outer and middle, except that the bolts are to be but one inch square.

Each outer angle of the crib is to be protected by a covering of wrought iron one inch thick, extending two feet each way from the corner, and from the top of the crib downward ten feet. These angle irons are to be fastened on by round wrought-iron one-and-a-half-inch bolts, one through every timber, on each side of the corner. The bolts are to be alternately long and short, the long being fastened through the middle timbers of the crib, and the short through the outer timbers, as shown on plans. The long bolts are to be used also in the lower part of the crib, from the bottom to the angle iron, in every other timber.¹

The spaces between the joists at the bottom of the crib are to be filled with gravel or broken stone flush with the tops of the joists. The joists are to be planked over with two-inch pine, fastened down with six-inch spikes.²

There are to be twenty-five pair of one-inch round wrought-iron rods to connect saddles placed under bottom timbers and over top ones, as shown on plans. The forms and mode of placing the saddles and connecting the rods with them and with each other are shown on plans. [These were not put in.]

The whole of the joints on the bottom of the crib, around the outside and central space of the crib from its bottom to within four feet of the top, and the joints around the inside of the three openings and their wells, are to be thoroughly calked with oakum and paid with tar.³

Each crib shall, immediately after being towed to its proper position, be secured by one-and-a-half-inch iron cables to five Mitchell's mooring screws, forced ten feet into the clay at the bottom of the lake. The dimensions and form of these screws can be seen on plans.

Each crib is to be filled with sound rubble stone, from its bottom to its top, as soon after being moored as practicable.

¹ On each side of each angle, from the bottom to the top of the crib, and in place of the sheeting, a piece of oak twelve by fourteen inches was put in the line of the long bolts. It was cut down to three inches under the angle irons. A corresponding piece of oak, three inches wide all the way, was put at the other ends of the bolts on the middle wall.

² This was all made of twelve-inch timber.

³ Every space from the bottom to the top of the crib, including the middle wall, was calked.

The angles of each crib shall be placed exactly in such positions as the board of public works may direct.

THE LAND SHAFT.—This will be located near and in the rear of the present pumping works of this city. From the surface of the ground to a depth of fifteen feet below the level of the lake, the shaft is to be twelve feet in diameter; and then it is to be contracted by a sloping offset of three feet all around to six feet diameter, to five feet below the bottom of the invert of the tunnel, a distance of sixty feet.¹

The whole of the shaft is to be lined with brick masonry twelve inches thick, where the shaft is twelve feet in diameter, and eight inches thick, where it is six feet in diameter, and on the invert at its bottom. The masonry of the offset is to be twelve inches thick.

The masonry is to be formed of hard-burned, clear-ringing, and well-formed bricks, entirely free from lime, not less than eight inches long, two and a quarter inches thick, and four inches wide, to be laid upright in cement mortar, and in rings or shells four inches thick. The courses must be horizontal, the inside surface of the shaft must be true and cylindrical, and the joints between the bricks not over a quarter of an inch on the inside of each ring.

The cement mortar is to be equal to the best of Clark's La Salle, and mixed with one measure of clean sharp sand to one of cement, and used as soon as possible after being mixed.

The joints between the rings must be not less than half an inch, and all the joints in the masonry must be perfectly filled with mortar at the time the masonry is laid.

Where the natural soil around the shaft is sand or loose material, there is to be not less than twelve inches of thoroughly puddled clay on the outside of the masonry.²

Whatever timber and lumber may be necessary to support the earth around the shaft, before the masonry can be built, must be furnished and put in by the contractor.

The pumping, and all labor and machinery connected therewith, must be done and furnished by the contractor.

INLET CYLINDER FOR OUTER LAKE SHAFT.—To be nine feet in diameter inside, and two and a quarter inches thick. To be made in sections of about nine feet in length, so that seven sections will make up the total length of the cylinder, or sixty-four feet. The flanges to be five and five-eighths inches wide by two and a quarter inches thick, and to be faced in the lathe true and at right angles to the center line of the cylinder. Each flange to have a small annular groove turned into the face, to receive the putty to be used in making the joint, as shown on the drawing. Flanges to be drilled for bolts one and a half inch

¹ The shaft was not executed in this way. Iron cylinders, three in number, and extending to a depth of thirty feet, were substituted. These were nine feet in diameter and one and a half inch thick. The shaft below was made eight feet clear diameter and twelve inches thick.

² All spaces were filled with either concrete or brick work in cement.

in diameter and about seven inches between centers. The lower section to be turned a taper of one-sixteenth of an inch, in nine inches from the end on the outside. The balance of the section to be accurately and truly turned parallel the entire length above the taper.

The second and third sections, and, if required, the fourth section, from the bottom to be accurately and smoothly turned,¹ each section of a diameter slightly in excess of the one next below it, say the sixty-fourth part of an inch, and should there be any difference in the diameter of opposite ends of the same section, then the largest end to be connected uppermost.

The section next below the top one is to be provided with openings for inlet gates, plans and specifications for which will be given to the contractor whenever necessary after one month from the letting of the work, and all additional expense to the contractor in making such opening will be paid for as extra.

INTERMEDIATE CYLINDERS FOR LAKE SHAFTS.—To be one to three in number, to be nine feet in diameter inside, and one and five-eighths inch thick. To be made in sections of about nine feet in length, so that seven sections will make up the total length of cylinder, whether sixty-five, sixty-six, or sixty-seven feet. The flanges to be five inches wide by one and three-quarter inch thick, and faced as specified for the "inlet cylinder." Flanges to be drilled for bolts one and a half inch in diameter, and about seven inches between centers. Three or four of the lower sections to be turned on the outside as may be required, and as specified for the "inlet cylinder." The sections to be stiffened by two intermediate internal flanges two and three-eighths inches wide by one and three-quarter inch thick. At the top of the third or fourth section from the bottom, as may be required, the flange to have a double width to receive a bonnet or head for closing and disconnecting the cylinder at that joint, as delineated on the drawing.

The iron employed in the construction of the cylinders to be of good quality. The castings to be sound and free from sand holes or other defects.

Bolts for connecting the cylinders to be made of the best wrought iron, one and a half inch in diameter, with hexagonal heads and nuts.

Joints between cylinder section flanges to be made air-tight with thin red lead putty. All necessary work, materials, machinery, and tools for completing and putting in place the cribs and cylinders to be done and furnished by the contractor.²

THE TUNNEL PROPER.—The clear width of the tunnel is to be five feet, and the clear height five feet and two inches, the top and bottom arches to be semi-circles. The tunnel is to be lined with brick masonry

¹ Only the lowest section was turned, the castings proving sufficiently smooth for the others without turning.

² The intermediate cylinders and shafts thus provided for were not found necessary and were not put in.

eight inches thick, in two rings or shells, the bricks to be laid lengthwise of the tunnel with toothing joints. The mortar, character of materials, and workmanship are to be like those described for the land shaft.

The excavation for the tunnel, when through sufficiently firm clay, shall conform exactly to the outside of the masonry on the bottom and sides. On top, just enough of excavation above the masonry will be allowed, to give room to turn and key the upper arch properly.¹ Sections of not over two feet of the upper arch are to be built at a time, and immediately after each section is keyed, the space above it shall be filled with earth, which shall be put into the space in small quantities at a time, and thoroughly rammed until it becomes as solid as the natural soil above.

Should a soil be met with in any part of the tunnel requiring the sides, bottom, and top to be planked and braced before the masonry can be built, filling in, carefully and thoroughly done, shall be put in between the masonry and the boarding, in or between the masonry and sides of the excavation, as is specified for the upper arch in a firm soil. The material for this filling may be dry sand or puddled clay.²

All timber and lumber necessary for bracing and supporting the sides of the tunnel and shafts, previous to the completion of the masonry, must be furnished and put in place by the contractor.

The contractor must furnish and put in place all necessary air-pipes and apparatus for ventilating the tunnel, all pumps, steam-engines, hoisting apparatus and fixtures for the same, all sheds and shelters for the protection of workmen and materials on the cribs, and all necessary tracks, trucks, and other necessary implements for machinery for removing excavated material out of, and building materials into, the tunnel.

The contractor must also remove all excavated material taken out of each shaft to such points as shall be designated by the board of public works, provided said points shall not exceed three hundred feet from any shaft, and must provide all necessary tug-boats, scows, and other means of transportation, and implements required for such removal.

GENERAL SPECIFICATIONS.—The contractor shall furnish and maintain such lights as may be necessary to avoid danger to navigation; and in case of failure to do so, shall be liable for all damages the city may have to pay on account of such failure.

All materials, of whatever kind, to be used in the work, are to be inspected by the board of public works; and all unsuitable materials are to be immediately removed from the work by the contractor.

The contractor shall discharge from his employment, when directed by the board of public works, all unfaithful and incompetent workmen.

The board of public works must be permitted to remove such por-

¹ In executing this part of the work, the masons soon learned to put in the masonry in clay ground without removing any more earth than was necessary for the regular arch.

² All the filling about the masonry of the tunnel was made with brick and cement.

tions of the work as they may, from time to time, think necessary for the discovery of improper materials or workmanship; and the contractor shall restore such work at his own expense, in case it shall have been done improperly; and at the expense of said board if done in a proper manner.

Any work, materials, machinery, or tools necessary for the completion of the tunnel, cribs or shafts, omitted in the plan and specifications, shall be done or furnished by the contractor, and paid for as extra work, at such valuation as the board of public works may make. This section is not to apply to the completion of the work as specified, but only to extra work, and no tools and machinery to be paid for unless ordered by the board for extra work.

The contractor shall furnish men and stakes sufficient to enable the engineer in charge of the work to give the necessary lines and levels to construct the work by.

The contractor must deliver to the board of public works, on or before the first day of each month, a written statement of the amount of extra work done and extra materials furnished during the previous month.

The contractor will be required to keep the work in perfect repair for twelve months after the same shall have been faithfully completed to the satisfaction of the board of public works.

Monthly estimates will be made by the board of public works of the value of work actually done and in its permanent place; and on or about the sixth day of each month seventy-five per cent. of the estimated value of the work done the previous month will be paid the contractor; the remaining twenty-five per cent. being reserved as security for the faithful completion of the whole work.¹

STATEMENT OF QUANTITIES OF MATERIAL IN THE OUTERMOST CRIB.²—38,814 cubic feet of white pine timber; 3,500 cubic feet of white oak timber; 20,251 feet, board measure, of white pine two-inch plank; 1,700 wrought-iron $1\frac{5}{16}$ -inch square bolts, 30 inches long; 120 wrought-iron 1-inch square bolts, 30 inches long; 200 wrought-iron $1\frac{1}{2}$ -inch round bolts, $13\frac{1}{2}$ feet long; 50 wrought-iron $1\frac{1}{2}$ -inch round bolts, 18 inches long; 200 square feet of 1-inch angle iron; 6,025 cubic yards of stone filling; besides 6-inch spikes, and paddle and other gates.

EXTRACT FROM THE AGREEMENT TO CONSTRUCT TUNNEL.

The agreement for the construction of the tunnel was executed on the 20th of October, 1863, the contractors undertaking to perform all of the work under the immediate direction and superintendence of the board

¹ During the progress of the work this provision was changed by vote of the city council, and eighty-five per cent. was paid upon monthly estimates for all work done, including the crib before it was launched.

² The quantities of these materials were considerably increased in consequence of the changes made during the progress of the work.

of public works of the city of Chicago, and to their entire satisfaction, approval, and acceptance.

The city of Chicago covenanted and agreed, "in consideration of the covenants and agreements in this contract specified to be kept and performed by the said party of the first part, to pay to said party of the first part, when this contract shall be wholly carried out and completed, the sum of three hundred and fifteen thousand one hundred and thirty-nine dollars, (\$315,139,) and for each foot of height that any one of the cribs for the protection of the lake shafts shall be built above the height stated in said plans and specifications, the sum of eight hundred and fifty dollars, (\$850,) and for each pound of addition made to the cast-iron cylinders for the like shafts above that stated in the plans and specifications, the sum of twelve (12) cents. It is also agreed, that during the progress of the work monthly estimates will be made by the board of public works of the value of the work done and in its permanent place, and that seventy-five (75) per cent. [changed, as already noted, by vote of city council from seventy-five to eighty-five per cent.] of the amount of such estimates will be paid to the said contractors as they shall be issued, and that the remaining twenty-five (25) per cent. shall be reserved as security for the faithful completion of the whole work, and shall be paid when this contract is completed, and the work accepted by the said board. It is further mutually agreed by the parties hereto, that nothing hereinbefore contained shall be so construed as to hold the said parties of the first part responsible for any accident or injury that may happen to either of the cribs or lake shafts mentioned in said specifications, after the same shall have been duly fixed and secured in their place, in consequence of any defect or insufficiency inherent in the original plan or design for the same, and not attributable in any degree to any defect or imperfection in the execution of said work by the said parties of the first part."

THE PROGRESS OF THE WORK.

Ground was first broken for the work on the 17th of March, 1864, when the construction formally commenced. The iron cylinders, which had been ordered to protect the land shaft against the influx of the very wet sand and gravel known to overlie the clay for about twenty feet, did not arrive till after two months of detention. The progress at first was much slower than was anticipated, owing to the troublesome nature of the sand and gravel; but the hard clay was reached about the first of April, and the iron cylinders had been sunk through the sand. No serious difficulty afterward arose in the prosecution of the land shaft and shore end of the work. At the end of the year the tunnel had been finished from the land shaft out under the lake 2,139 feet, and July 10, 1865, it had reached 3,023 feet, and was extending outward at the rate of about twelve feet per day. August 25 it had reached a distance of 3,505 feet, and the masonry was about twenty-five feet behind the face.

In some places an average rate of progress of fourteen feet per day was made for a week at a time, but for the whole period this average was considerably less, owing to occasional interruptions from the breakage of machinery, strikes among the workmen, the meeting with and occasional explosion of gas, and other causes. The average for the year ending April 1, 1865, was thereby reduced to nine and one-tenth feet per day. The character of the ground was nearly uniform.

The back filling between the regular brick-work and the irregular surface of the excavation of the tunnel, which was originally intended to be of well packed earth, was made of masonry, because it was found very difficult to get the puddled clay used faithfully packed into the spaces. The ground generally was so uniform and favorable for excavation that the tunnel was cut with great precision, and an average of one inch thickness of cement mortar between the bricks and the clay walls was all that was required.

A tendency in the clay to swell was found at an early stage of the work, but the masonry resisted it perfectly. It, however, gave some trouble in the grading, for one portion would swell more than another. In order to facilitate the work, chambers and turn-tables were placed at intervals of one thousand feet. These were used for the storage of materials and for mixing cement, and for turn-out tracks for the cars. As the work progressed iron rails were substituted for wood in the tramways, and small mules were used to draw the cars instead of men. By all these facilities the economy and rapidity of execution of the work were increased.

VENTILATION.

The ventilation of the first half mile of the tunnel was effected by drawing the vitiated air out through a pipe connected with the chimney of the boiler furnace, but toward the last this method was found to be so ineffectual and unreliable that it was abandoned, and one of Alden's blowers was used with complete success.

PLACING THE CRIB.

The crib through which access was to be obtained to the bed of the lake for the excavation of the tunnel from that point shoreward, simultaneously with the progress of the shore end, was not placed in position before the 25th of July, 1865, when it was launched and towed out to its place in the lake. The work of sinking was delayed somewhat in consequence of defective arrangement of and accidents to the anchors. Just as it reached the bottom a storm came on, and as the crib was not sufficiently loaded to rest firmly upon the bottom, it was filled with water by means of a wrecking pump. After the storm had subsided, it was found that the crib had moved thirteen feet north of its true position, and that it had become firmly imbedded in the clay of the bottom of the lake. It was therefore deemed best not to disturb it, as the variation from the

exact position was of no practical importance, and it was immediately filled with stone. It was afterward built up three feet higher, so as to be secure from the wash of the waves, and it was covered in by a building to serve for the protection of the workmen, the materials, and machinery. The seven iron cylinders making the iron part of the shaft, and sixty-three feet of it in height, were connected together, one by one, and lowered inside of the crib to the bottom of the lake, within the thirty feet wide open space in the center of the crib. The gates or valves, by which the water of the lake is admitted to these cylinders, are placed near to their upper end.

After the cylinders had been placed in the right position, they were forced downward into the clay some twenty-five feet, the water being wholly excluded. The masonry was then commenced. In the mean time the engine for hoisting and the necessary machinery were made ready, and the bricks, cement, and other materials and supplies were collected and stored in the building upon the top of the crib. For all these preparations a much longer time was consumed than was anticipated, and the work upon the tunnel at that end did not commence before the 1st of January, 1866, after which the work steadily progressed.

The material, through which this outer portion of the tunnel was excavated, was found to be similar to that at the in-shore end—a stiff, hard clay.

By August 15, 1866, the in-shore part of the tunnel had progressed 7,160 feet, and the outer or lake end 1,725 feet, leaving of the two miles, or 10,560 feet, only 1,675 feet to be excavated. This shows a progress at the land-shaft end of 5,135 feet since April 1, 1865, which, for a period of 427 working days, gives an average of twelve feet per day, including all stoppages of whatever nature. Frequently the rate was fifteen feet a day for a week at a time.

In commencing the lake-shaft end of the tunnel, it was excavated for about sixty feet to the eastward, in order to facilitate the alignment. The ground at the lake end was found to be very similar to that at the other, but more liable to cave in, and consequently rather more difficult and expensive to work.

COMPLETION OF THE TUNNEL.

On the 24th of November, 1866, the two parties which had been slowly nearing each other in their work of drifting and lining the tunnel, the one working from the shore shaft outward and the other from the lake shaft inward, were separated from each other by a thin wall of clay about two feet thick, 8,277 feet from the shore shaft and 2,290 feet from the lake shaft. On the 30th this barrier was removed, and the engineers passed through from one end of the tunnel to the other. When the work of the two parties was brought together, the two portions of the tunnel were found to coincide almost exactly both in line and level, the

alignment varying but seven and three-fourths inches and the levels agreeing.

The masonry uniting the two parts of the tunnel was formally closed up December 6, 1866, by his honor Mayor Rice, and the citizens were permitted to inspect the work. There then remained the side chambers to be filled up and the entire tunnel to be cleaned out. This was all carefully done, and the water was first let into the tunnel from the lake on the 8th day of March, 1867, and on the 11th it was filled to the level of the lake. The water was then pumped out sufficiently to allow a boat to pass upward of half way from the crib to the land shaft. Not a brick was found to be displaced, and it could not be perceived that the slightest fracture had anywhere taken place by the pressure to which the masonry had been subjected. As it was very desirable to use the tunnel as soon as possible it was thought unnecessary to pump out the whole of the water, and the tunnel was again filled. The formal and public opening took place on the 25th of the month, and since that time Chicago has been free from the annoyances of impure and fetid water.

It is an interesting fact that this tunnel, like the Croton and Cochituate aqueducts, is found to deliver more water under a given head than the formula in common use calls for.

The following summary shows the number of days occupied in constructing the tunnel, the amount of excavation, and the quantity of materials, used:

Time and materials required in the construction.

Description.	Days occupied.	Excavation.	Brick work	Bricks.	Cement.
		<i>L. feet.</i>	<i>L. feet.</i>	<i>No.</i>	<i>Barrels.</i>
Extension west.....	37	144	144	43, 193	259½
Land shaft.....	31			32, 000	114
Lake tunnel (center to center of shafts).....	955	19, 567	10, 567	2, 393, 224	9, 582½
Lake shaft.....	17			10, 207	31
Extension east.....	19	65	65	20, 880	106
Eight chambers.....	35			51, 250	246½
Grand totals.....	1, 094	10, 776	10, 776	2, 550, 754	10, 339

The total cost of the lake tunnel at the time of its completion amounted to \$457,844 95.

This amount is made up of the following items:

Engineering and superintendence.....	\$28, 744 02
Printing and advertising.....	375 13
Miscellaneous.....	6, 250 03
Labor.....	2, 096 20
Lumber.....	1, 142 72
Piles.....	1, 258 29
Hardware.....	53 85
Castings.....	597 55

Lake shaft gates and chambers	\$12,629 86
Dredging for crib	1,500 00
Tugs for board and employés	6,718 17
Discount on bonds	14,685 35
Opening celebration.....	979 18
Dull and Gowen, (contractors).....	380,784 60
Total	<u>457,844 95</u>

It appears from the statements and books of the contractors that the actual cost of their work, deducting profits, was not more than \$330,500. The crib and outer shaft cost \$117,500; the land shaft cost \$12,000; the west extension and connection with the gate-chamber, no part of the original contract, cost \$6,000, leaving \$195,000 as the cost of the tunnel proper. This being 10,567 feet long made the cost to the contractors \$18 45 per lineal foot. The usual prices paid for labor were, for laborers, \$2; masons, \$5; engine men, \$3 per day; for brick, \$14 per thousand; for cement, \$2 75 per cask of 300 pounds.

ENGINE HOUSE AND PUMPING ENGINES.

Upon Plate I, which is somewhat crowded with figures, will be found plans, sections, and elevations of the tunnel, and particularly of the pumping works and engines. The upper figure shows, upon a small scale, a general plan of the whole line of the tunnel, with a plan of the pumping works and the old inlet-basin from which the water was formerly pumped at one end, and the crib or lake shaft at the other end.

In the right-hand lower corner of the plate will be found a section of the shore end of the tunnel, with the connecting shafts, pump well, pumping engine, the water tower, and connecting pipes. This section is along the line C D of the plan above it, which shows the general arrangement of the works and buildings, the direction of the shore inlet and of the end of the tunnel. An enlarged plan (scale $\frac{1}{370}$) of the engine house is given in the center of the lithographic plate, with a front elevation of the building and of the water tower upon the same scale in the left-hand lower corner.

The buildings for the pumping engines and water column are unusually commodious and beautiful, and are constructed of stone in the castellated style, from designs by W. W. Boyington, architect. They are shown in elevation and in plan upon a scale of $\frac{1}{370}$ upon Plate I. The building has a frontage of 148 feet in length and a depth of 144 feet 9 inches. Only one end is yet occupied by the pumping engines, space being reserved for others, which it is expected will be required before the year 1875. The site reserved is shown in the plan as also the places which were occupied by the engines erected in 1855 and in 1857.

One of the pair of pumping engines now in use is shown in section upon a scale of $\frac{1}{182}$. It is a double-acting pump twenty-eight inches in

diameter and eight-foot stroke. The cylinders are forty-four inches in diameter and the stroke is the same as in the pumps. They take the water from a sump, or well, lined with brick and communicating by means of a curved tunnel with the main lake tunnel through the shore-end shaft, as shown upon the plan.

Upon Plate II will be found plans and sections of the crib and lake shaft, and its connections with the tunnel below, also details of the construction of the inlet gates and bulk-head. These plans and sections of the crib show the method of framing and bracing, and the filling with stone. The combined vertical section of the crib and shaft is upon a scale of $\frac{1}{184}$. The details of the tunnel inlet gates and the bulk-head are upon a scale of $\frac{1}{75}$. The details of construction of the chamber gates at the shore end are given upon Plate I.

IV.—THE SUEZ MARITIME CANAL.

HISTORICAL NOTICE.

The project of establishing water communication between the Mediterranean and the Red Sea is not a modern idea. Sesostris, who reigned in Egypt about 1700 B. C., is believed to have cut the first canal leading from the Nile to the Red Sea. This canal was reopened by Necho and Psammiticus about 650 B. C., and was repaired by Darius seventy-five years later. The Roman emperors Trajan and Adrian caused a branch to be dug to the main body of the Nile, and continued the canal to Suez. In the year 780, or about that time, the canal was partly filled up, and since the conquest of Egypt in 1380 the canal has been wholly abandoned. In 1799 Napoleon had a line of surveys extended across the isthmus, to ascertain the difference of level, if any, between the two seas. His engineer, who worked hurriedly and without proper instruments, reported a difference of nearly thirty-three feet. In 1847 M. Bourdaloue, a French engineer, ascertained that the difference of mean tide in the two seas amounted to only six and a half inches.

In 1854 Mr. Ferdinand Lesseps was authorized by Mohammed Said, for the Egyptian government, to form a company for the purpose of digging a ship canal from sea to sea, with the exclusive right of transit for ninety-nine years from the day of completion. The canal was begun in 1859 by Mr. Ferdinand Lesseps, and, at the date of this publication, is open to the commerce of the world.

The nature of the region over which the canal passes, the topography, the geology, the machines used in excavating, and the details of the construction were most fully shown at the Exposition by means of models, plans in relief, maps, photographic views, and descriptive publications. It is from the latter that the following descriptive notices have been chiefly compiled.

THE ROUTE OF THE CANAL.

But before proceeding to give some details of the construction and working of the various apparatus, a bird's eye view of the great work is desirable.

The canal is one hundred miles long, and extends nearly north and south from Port Said, on the Mediterranean, to Suez, on the Red Sea. The isthmus at this place is low, and the canal follows a marked depression or valley, and for a great part of the distance is dug in the beds of shallow lakes, and traverses the dried-up basins of former lakes so far below the level of the adjoining seas that little or no excavation is required. The highest ridge or plateau is El Guisr, some ten miles wide, and rising to a height of about sixty-one feet above the sea level. Here a cutting some eighty-seven feet deep was required.

There is abundant evidence that at a comparatively modern geological epoch the two seas, if they did not unite through these remarkable depressions, at least approached so nearly that the isthmus was contracted to the plain of El Guisr, while the Mediterranean, filling the basin of the shallow lakes, washed the dunes of El Ferdane; and the Red Sea, by the Bitter Lakes, reached the opposite side of this narrow plateau. Numerous shells, similar to existing species, found fossil in the interior, and abundantly distributed over the surface, confirm the accuracy of this view. Mr. Lesseps thinks that this was the place crossed by the children of Israel, led by Moses and Aaron.

The greatest length of the basin of the Bitter Lakes is about twenty-two miles, and it varies in width from two and a half to five miles. The depth below the sea level ranges from eight to nine metres, about thirty feet. This vast depression has been filled through the canal by the waters of the adjoining seas. It is computed that this basin contains nine hundred millions of cubic metres of water, and it now forms a vast interior lake, where the navies of the world may float in safety. It has been a dry and parched desert from time immemorial, and its bottom was covered with salt and crusts of gypsum, in fantastic forms. It now serves not only as a convenient waiting place for vessels, but equalizes the flow of the waters caused by the tides and the prevalence of northwest winds, and thus renders locks or gates in the canal unnecessary.

MATERIALS THROUGH WHICH THE CANAL IS EXCAVATED.

The materials through which the excavation of the canal has been made are generally soft and unconsolidated, being the sands and finer sediments of the delta of the Nile, overlaid by the accumulation of sand thrown up by the action of the Mediterranean. At Port Said a littoral cordon of fine sand separates the Mediterranean from Lake Menzaleh, a shallow expanse of water, dotted with low sandy islands, which appear to be remnants of ancient sandy beaches, and to rest upon lacustrine clays. Passing the Ballah Lakes (often without water) to El Ferdane, the surface becomes undulating, and the formations consist of sand, in-

terstratified with beds of clay. In some places the sand is cemented so as to form true sandstone. Upon the plateau of El Guisr is the city of the same name, built by the company. From this place the view to the east and south comprises the deserts and mountains of Syria in the distance. The plateau des Hyènes, the Djebel-Mariam, and certain parts of the plain on the east of Lake Timsah, afford limestone suitable not only for burning but for construction.

As there was no port or protection for shipping upon the Mediterranean side, it became necessary to make one. This has been done by throwing out two piers or breakwaters, one two and a half miles long, the other one and a half mile long; one projecting beyond the other, but giving a clear passage into the harbor a quarter of a mile wide. The shore ends of these piers are about fifteen hundred yards apart; a triangular space is thus secured, land-locked, and gives a safe and commodious harbor, the best of any upon the eastern shore of the Mediterranean.

EXTENT OF THE EXHIBITION MADE BY THE COMPANY.

The exhibition made by the Isthmus of Suez Canal Company occupied a separate building in the park of the Exposition, and comprised: First. Plans in relief, photographs, drawings, models, machines, and charts, giving a general representation of the scene of operations, the means employed to carry them into execution, and the system of traction for the transport of merchandise from one sea to the other. Second. Various collections illustrating the natural history and geology of the Isthmus of Suez. Third. A diorama, showing that part of the isthmus crossed by the canals of the company.

FIRST PART.—No. 1. A relief plan of the isthmus, and a part of Lower Egypt, with the system of canalization of the delta of the Nile; the line of the railway from Cairo to Suez; the development of the fresh-water canal, and the cutting of the maritime canal across the Isthmus of Suez. No. 2. Plan in relief of the port and town of Port Said, erected by the company; entrance of the canal in the Mediterranean, with representation of the works. No. 3. Plan in relief of the town of Ismailia, located and built up by the company in the center of the isthmus, on the margin of Lake Timsah, at the point of junction of the maritime canal with the canal of fresh water derived from the Nile—the administrative center of the works. No. 4. Plan in relief of the port and town of Suez, and entrance in the Red Sea of the fresh and salt water canals, with representation of the works. No. 5. Plan in relief of the plateau of El Guisr, which is the most elevated point of the isthmus on the line of the maritime canal. This plan represents in detail the works in course of execution, and shows the cutting by means of which the company fills Lake Timsah from the Mediterranean. There are also shown the establishment of sheds for the excavators, the system of digging by manual

labor, and the earthworks and trucks. No. 6. The general plan of an establishment at Ismailia, containing the machinery for raising and distributing fresh water along the whole line of works from Ismailia to Port Said, by means of three steam-engines and two conduits, executed by Mr. Lasseron, contractor for the company. No. 7. A large model of the canal, on the scale of three in one hundred, on which were placed models of the principal machines employed in the excavation of the maritime canal, in their proper positions; that is to say, A, a dredging machine, excavating, and at the same time throwing up the earth to a considerable distance, (designed by Messrs. Borel and Levalley, contractors under the company, and constructed by the Society of the Forges and Works of the Mediterranean;) B, an apparatus connected with the dredging machines for throwing the earth over the banks when the latter are too high for the action of the dredges themselves, (plan by Messrs. Borel and Levalley, and executed by the same company;) C, a great lighter, intended to transport cases full of the excavated earth from the dredging machines to the elevating apparatus, (planned by Messrs. Borel and Levalley, and executed by Messrs. Gouin & Co. ;) D, vessel employed to convey to the open sea, or to the middle of the lakes in the interior, the earth excavated by the dredging machines in those parts of the canal which are near the lake or the sea, (executed by Messrs. Henderson, Coulhorn & Co., and Mr. Thomas Bollin Seath, of Glasgow;) E, a lighter with side clap-valves, used for the same purpose as the previous vessel, with this difference, that the lighter being especially intended to carry the earth in the lagoons or basins in the interior of the country, is discharged by the side, (designed by Messrs. Borel and Levalley, and executed by Messrs. Gouin & Co. ;) F, a dry excavator or dredging machine, employed at El Guisr. This apparatus is backed against the part upon which it operates, and throws the earth into trucks, brought to it by a locomotive, (planned by Mr. Couvren, contractor under the company, and executed by Mr. Galbert, of Lyons; the trucks by Messrs. Maize, Voisine, and Touchard, and the locomotives at Creuzot;) G, a tug intended to tow the daily trains carrying merchandise from Port Said to Suez, and *vice versa*, by the company's canals, (planned by Mr. Bouguié, and executed by Messrs. Claparede & Co., of St. Denis.) No. 8. A series of photographs, drawings, and charts, used in the preparation of the plans, in relief, and also the diorama representing the various works on the isthmus.

SECOND PART.—No. 1. A geological collection of the various soils found along the whole line of the salt-water canal, from one sea to another, (collected by Mr. Laurent Degousée, after the indications of M. Elié de Beaumont, senator.) No. 2. A collection of objects in natural history, and other things collected in Egypt, namely, medals and ancient coins, statuettes, pottery, mineralogy, shells, fossils, madrepores, petrifications, reptiles, and butterflies. This collection, which belongs to the museum of Perphignan, and which the municipal council of that

town kindly lent to the company, was collected in Egypt, and presented to his native town by Dr. Companys, jr., physician to the Suez Canal Company. No. 3. A collection of objects of natural history, plants, crustacea, mineralogy, insects, madrepores, fishes, and birds. This collection was made on the isthmus, and also in the waters of the Mediterranean, at Port Said, and in the waters of the Red Sea, at Suez, and at various interior lakes, by Captain Baudouin.

THIRD PART.—The diorama, executed by Roubé, decorator of the opera, under the direction of Mr. Alfred Chapon, architect to the company, after a complete and numerous series of photographs, shows from one end to the other the whole of that part of the isthmus which is traversed by the company's canal, as it exists at the present day, with the towns, the workshops, the machines, and the entrance-ports of the canal on the Mediterranean and Red Sea, Port Said and Suez.

THE DIMENSIONS OF THE CANAL.

The canal is 8^m.00 deep below the water-line. The breadth of the bottom ("plafond") is everywhere 22^m.00, but at the water-level it is 58^m.00, in that portion traversing El Guisr, Sérapéum, and Chalouf, a distance of about 33 kilometres in all. In other portions the breadth is 100^m.00.

The slope of the talus is determined in each region traversed by the canal by the nature of the earth and materials thrown out. The inclination is never less than two of base to one in height.

In those portions where the breadth is only 58^m.00 there is on each side, one metre below the surface of the water, a bench or causeway 2^m.00 wide, and where the breadth of the canal is 100^m.00 the breadth of the bench varies with the natural slope of the talus. The form of the section varies with the height of the banks and the nature of the materials. The annexed figures show the form at the ridge of El Guisr and

Fig. 1.

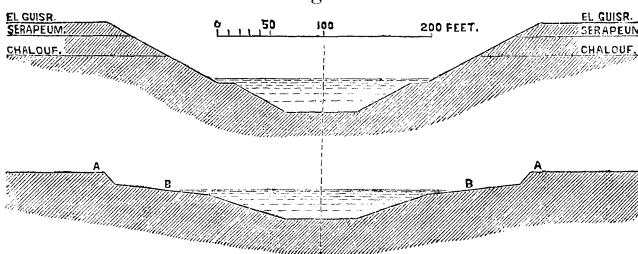


Fig. 2.

at the shallow lakes and low ground. Fig. 1 is the section across the canal at the high ground, and it indicates also the levels of Serapeum and Chalouf. Fig. 2 shows the form of the banks adopted to prevent washing down by the waves. The banks A A are 394 feet apart, thus leaving a low shelving bank B B. In order to deposit the dredgings at such a great distance as the banks A A, on each side, it was found necessary to resort to the use of dredges with long chutes.

THE GREAT DREDGES.

The following are the dimensions and general arrangement of the great dredges made for the company: Length of hull, 30^m.00; breadth, 8^m.00; depth, 3^m.00; draught of water, 1^m.60. The hull is of iron. The engine of each dredge is vertical, direct-acting, condensing, with two cylinders, and nominally 35 horse-power. The total heating surface of the boilers is 81 square metres. A single line of dredge buckets is supported in the center, the upper roller being 8^m.50 above the water level. This line of buckets is 19^m.50 long, and in some of the dredges the buckets have a capacity of 350 litres and in others 300 litres. The lower roller or bearing, over which the buckets pass, can be elevated and thrown forward of the boat so that an excavation may be made in advance where the banks are above the bottom of the hull.

These twenty dredges were supplied with ordinary chutes for the delivery of the earth into barges at the side, but afterward longer chutes were constructed so as to deliver the materials at a distance of 25^m.00 from the dredge. Even these long chutes were found insufficient, and forty other dredges were ordered, four of them made with chutes 60^m.00 long, eighteen with chutes 70^m.00 long, and the others with the ordinary chutes. These dredges resembled in their general construction the first twenty, but the length of the hull was increased to 33^m.00; the breadth to 8^m.30; the depth to 3^m.16, and the draught reduced to 1^m.50. The engine had the same nominal power, exerting easily upon the pistons a force of 7,875 kilogram-metres. The boiler had a heating surface of 108 square metres. The dredge buckets had a capacity of 400 litres in some, and 300 in others. The dimensions of the transverse section of the links which united these buckets into an endless chain were 0^m.18 by 0^m.058. The bolts were of tempered steel, and the eyes were bushed with steel, also tempered; the holes being 0^m.07 in diameter. The dredges with the ordinary delivery chutes had the upper roller placed 11^m.50 above the water; and those with the chutes 60^m.00 long had theirs at the same height, but those made with chutes 70^m.00 long were raised higher, to 14^m.80 above the water level.

The construction and general arrangement of these dredges with long chutes is shown by the accompanying figures. Fig. 3 is a vertical section and Fig. 4 a plan. The chutes are sustained by lattice girders, and they are supported upon a barge moored parallel to the side of the dredge, and in such a manner upon telescopic supports that they may be raised or lowered at pleasure by means of a hydraulic hoist, and thus be inclined at different angles.

The attachment of the chute to the dredge is not rigid but permits of much movement, and is formed by a horizontal hinge which permits the change of inclination when the chute is raised or lowered upon the barge. The supports on the barge are so made that the chute can be turned horizontally and thus be placed parallel with the canal in order

that with one end resting upon another barge it can be moved from one place to another with ease.

The section of the chutes has the figure of a half ellipse 0^m.60 deep and 1^m.50 wide.

Two rotary pumps placed upon the dredge, and driven by the engine, throw a stream of water into the upper end of the chute, so as to wash the dredging down the slope. In case these pumps do not supply sufficient water to effect this washing out with some kinds of earth, the barge which sustains the chute also carries a portable engine working a pump capable of giving 150 cubic metres of water an hour. The water from this pump is delivered into the chute along its entire length by means of a pipe pierced with holes. In addition to this, an endless chain furnished with scrapers is made to move along the bottom of the chute whenever the materials are too stiff to be freely discharged by the aid of the water. Fine sand descends rapidly with an inclination of from 0^m.04 to 0^m.05 to the metre, when washed with a quantity of water equal to half of the material dredged. For clays, a slope of at least from 0^m.06 to 0^m.08 to the metre is required, but less water is necessary.

The annual delivery of silt, sand, &c., by the dredges

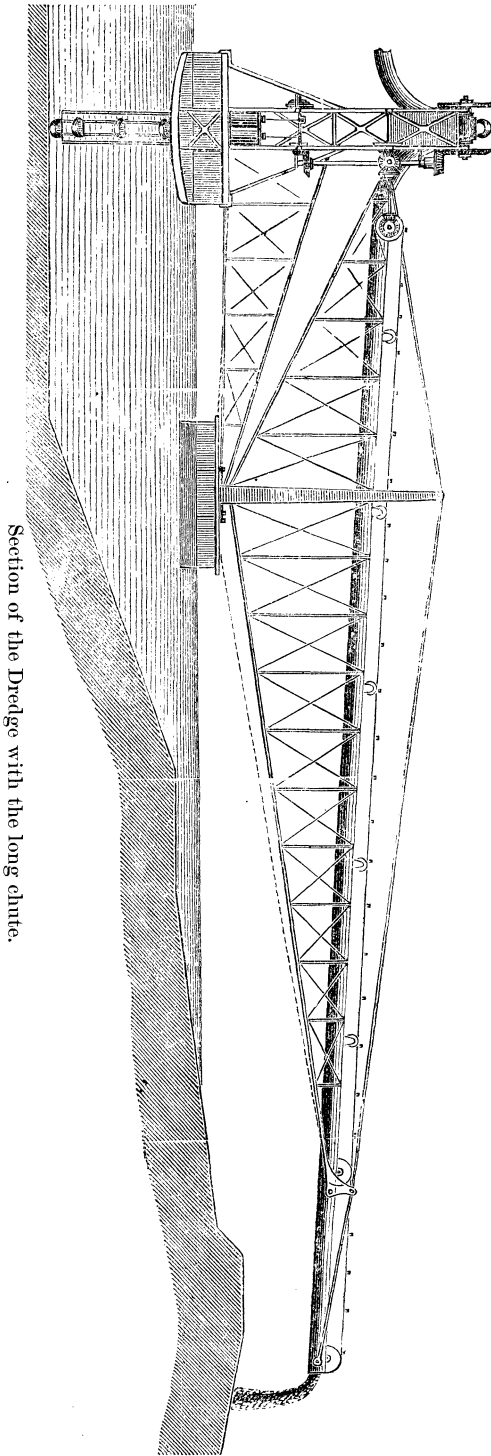
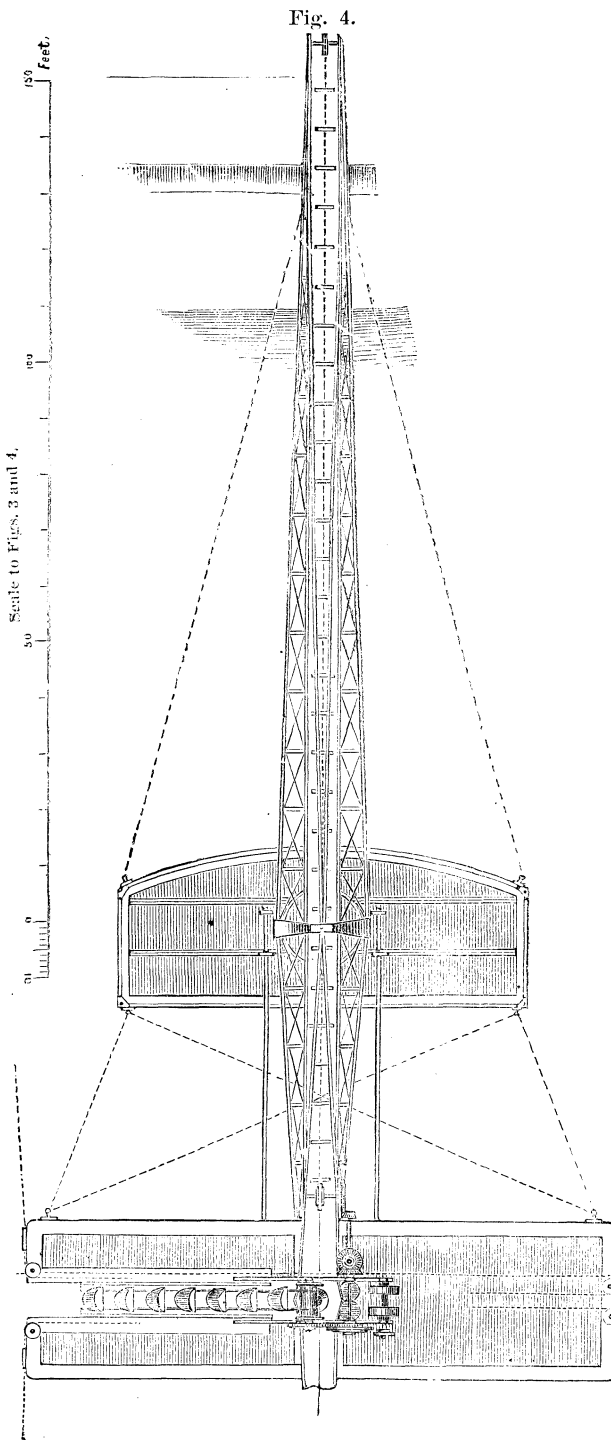


Fig. 3.



with the long chutes may be estimated to be at the least 350,000 cubic metres; that of the dredges, with the ordinary system of delivery, may be estimated at 300,000 cubic metres.

The slope of the exterior of the banks (*cavaliers*) deposited by the long chute varies from four to seven in one hundred according to the nature of the materials delivered, whether sandy or clayey and more or less compact. This great slope is due to the velocity of the water by which the materials are discharged, and it allows a great quantity of dredging to be disposed of without making a high bank.

These long-chute dredges are very simple and economical. They can be employed wherever the ground is not too high, and they do not cease to deliver the dredgings until the accumulation becomes too high for the lower end of the chute. They were used for nearly all that por-

tion of the canal which traverses Lake Menzaleh, and for portions which traverse the plain of Suez, and the margins of the great lakes.

ELEVATING APPARATUS.

In those portions of the canal where the ground was too high to permit the long-chute dredges to be used, the elevating apparatus about to be described was substituted.

The attempt was first made to work with cranes placed upon the banks and having thirty-three feet radius of swing, by the aid of which boxes filled with the dredgings were lifted and swung out to the banks and dumped or emptied into a train of wagons on a tramway.

The elevating apparatus may be described as a portable inclined railway, extending from the dredger or barge loaded with dredgings, upward over the banks, and upon which trucks or "trolleys" carrying the boxes filled with the dredgings were made to ascend, and finally to dump the contents at the further end. The contrivance is but another form of the long chute, the difference being that the slope is reversed and the track and trolleys take the place of

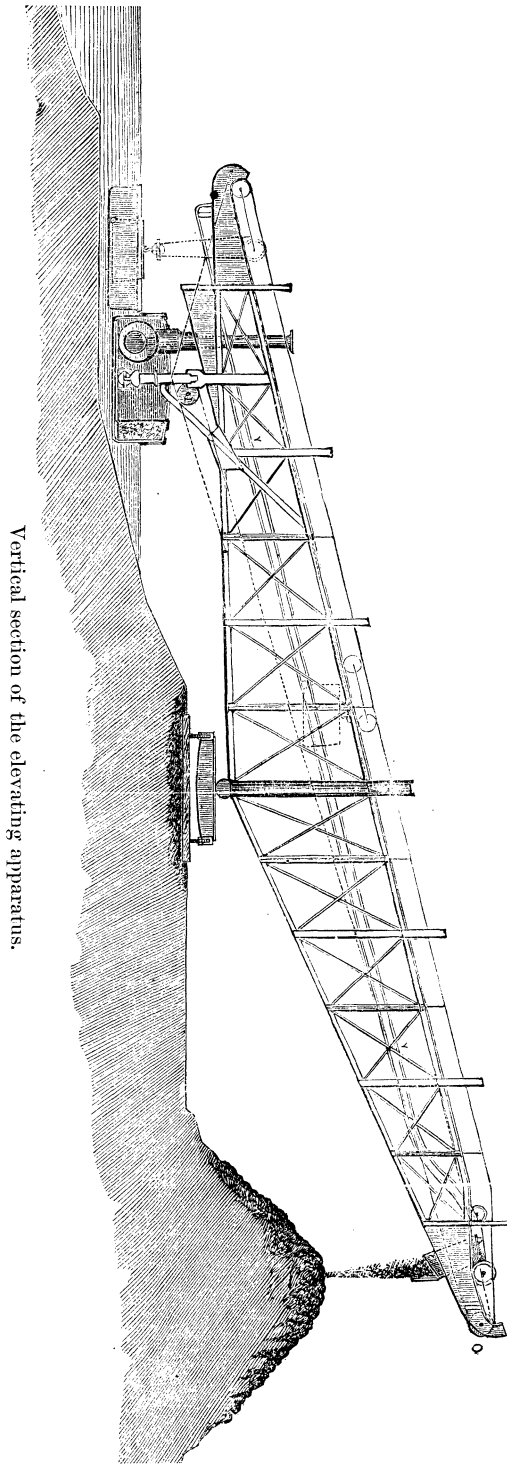
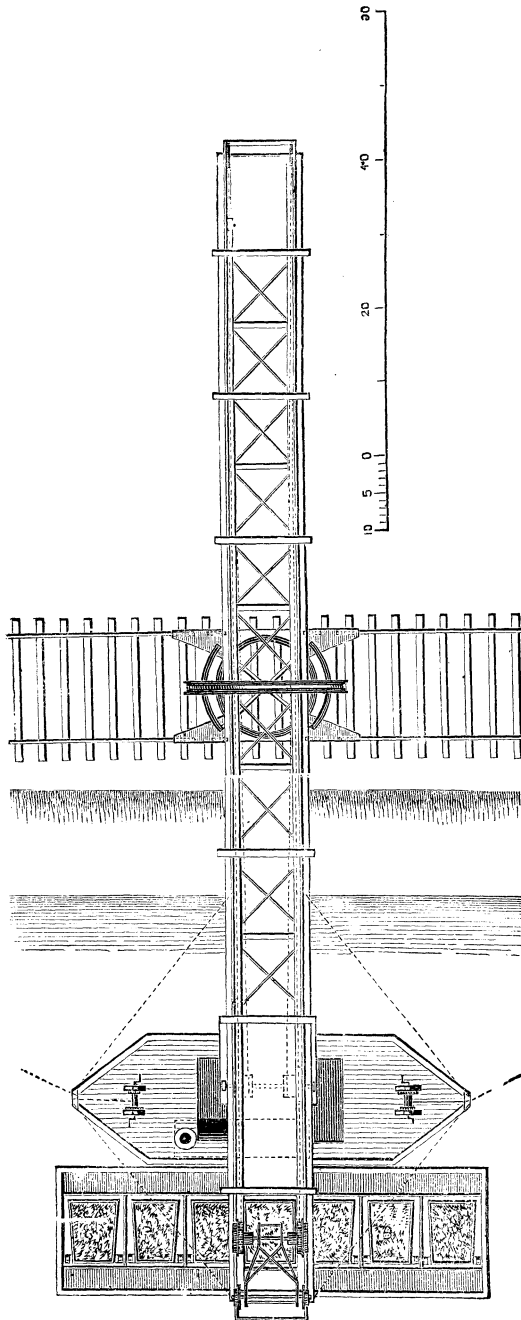


Fig. 5.

the chute along which, where the banks are low, the dredgings descend by gravity. Like the long chutes, the inclined tramway is supported

Fig. 6.



Plan of the elevating apparatus.

about midway, not upon a floating barge, but upon a strong truck running upon a railway laid upon the bank and parallel with the course of the canal.

The two figures, Fig. 5, a vertical section, and Fig. 6, a plan, will give an idea of the construction of the apparatus.

The tramway is supported by two parallel lattice girders tied together by vertical struts and united above the track by arched ties. The length is about 150 feet, and the inclination is about $0^m.22$ per metre. The lower end is about $3^m.00$ above the surface of the water and the upper end over the bank is about $14^m.00$. The bank upon which the track carrying the truck is laid is raised about $2^m.00$ above the water. The lower end of the tramway rests upon a barge; the upper end is quite free and is at such a height above the bank that there is plenty of room for the accumulation of the dredgings.

When the apparatus is put into operation a float carrying the boxes of dredgings is floated under the lower and projecting end of the apparatus, and a box is hooked on to the trolley which is at the bottom of the track. A steam-engine upon the barge supplies the power for draw-

ing the trolley and box up the incline and for tipping the box at the upper end.

The construction of the trolley is shown in Fig. 7, a side view, and Fig. 8, an end view. *NN* are the rails of the tramway, *R* the frame of the trolley, and *UU* the boxes of dredgings. The wheels are external, and the lower two are fixed upon the axle while the upper are loose, and the axle carries two larger wheels *TT* and drums *SS*. Upon these small drums *SS* the chain is coiled by which the boxes are supported, while on the larger drums *TT* iron cables are coiled in the opposite direction. These cables pass over a pulley *O* at the upper end of the elevator, and then return to the winding drum of the engine. When this cable is wound upon the engine drum it uncoils from the drum *T*, and by means of the chain winding upon *SS* raises the box vertically from the float until a stopper or guard *VV* comes in contact with the drum *S*, when the coiling upon *S* ceases and the trolley begins to travel up the incline as the cables unwind from *T*. When the trolley and suspended box reach

Fig. 7.

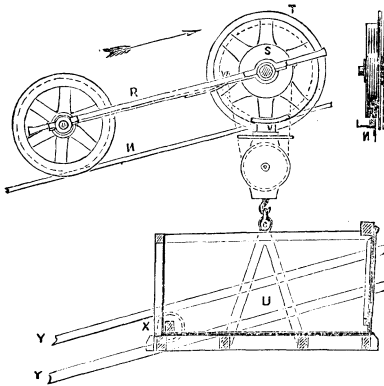
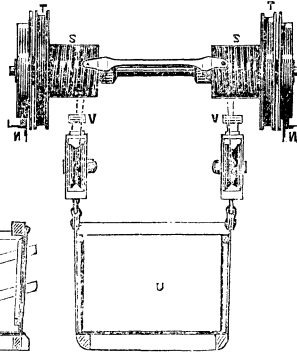


Fig. 8.



the upper end of the incline the box is tipped automatically, by means of rollers *X* running between guide rails *YY*, and which curve suddenly upward and thus raise the back end. The same guides serve to keep the box horizontal during the ascent.

RAFT BARGES.

For carrying the boxes filled with the earth, delivered by the ordinary dredges, rafts were used. These were made of two long water-tight boxes of sheet iron, 17^m.50 long, 1^m.10 wide, and 1^m.25 high, kept at a distance of 3^m.00 apart by means of eight open-work partitions, between which the boxes for the reception of the dredgings were placed. These boxes when filled were nearly submerged in the water. This arrangement has several advantages, not the least of which is that by being so low the chutes may be more inclined and the height of the dredge may be less. Ninety of these rafts were made use of.

VESSELS FOR TRANSPORTING THE SAND.

In the vicinity of the sea, and in the deep portion of the lakes, where the dredgings could not be deposited in *cavaliers* upon the sides of the canal, they were taken and emptied in the sea or the lakes by means of screw-propeller vessels called *bataux porteurs*. Of thirty-six of these boats ten were built in England and twenty-six in France. Those made in England are similar to those which are used upon the Clyde and the Tyne, and have, in general, the following dimensions: Length of hull, 41^m.15; breadth, 7^m.01; depth, 2^m.97; length of the hold or pit, 15^m.24; breadth of the hold at the level of the bridge, 5^m.79; breadth at the bottom, 2^m.51.

The pit or hold for the reception of the dredgings is central, and its capacity is about 180 cubic metres. It is closed at the bottom by six pair of trap-doors opening downward, held by chains which are wound around pulleys placed in a frame above the doors. The engine is nominally 50 horse-power, condensing, and works a screw 2^m.438 in diameter. The speed of these vessels is from six to seven knots an hour. The boats made in France have a capacity of 200 cubic metres. Twelve of these have the hold central; the others have it double, a pit in each side.

For those portions of the work where the dredgings could not be deposited in banks *en cavalier*, and where the water was shallow, lighters with doors or valves at the side were used instead of the vessels with valves at the bottom. These lighters, called *gabares à clapets latéraux*, are built entirely of iron, and are 32^m.50 long and 6^m.00 wide. The hold for the dredgings, divided into six compartments, is 20^m.00 long. It is divided along the center by an air-tight compartment of triangular cross-section, of which the bottom of the lighter forms one side. The length of the side clap-valves is the same as each compartment. They are 1^m.20 high and are hinged at the top. These lighters are provided with double-cylinder, horizontal, high-pressure engines, and they carry from 80 to 90 cubic metres of dredgings and draw 1^m.20 of water.

DRY EXCAVATORS.

This apparatus upon dry and elevated soils takes the place of the dredgers used for wet ground. It excavates the earth and delivers it into wagons placed upon a tramway. It was used at the ridge or plateau of El Guisr to enlarge the trench cut by the Egyptian laborers. The apparatus consists of a horizontal framework, a staging, supported by nine wheels upon a railway or tramroad of three rails, running parallel to the bench to be enlarged. This framework or carriage is 6^m.00 long and sustains a boiler and two engines. One of these engines is used to put in motion a chain of excavating buckets, and the other to move the apparatus.

There are eight buckets, and they discharge the earth into a chute, which projects 3^m.00 beyond the exterior rail and delivers into the wagons placed on a second and parallel tramway.

The weight of the apparatus is nearly 22,000 kilogrammes. The engine is fifteen horse-power. The amount excavated and delivered reaches 750 cubic metres in ten hours, in sandy soil, of little resistance. When, by means of these dry excavators, the cut was carried to the water level, the remainder of the excavation was cut by the dredges.

ARTIFICIAL STONE PIERS AT PORT SAID.

For the construction of the piers at Port Said stone blocks from quarries near Alexandria were at first employed. It was found, however, that the cost was too great, and it was decided to manufacture blocks of stone out of the beach sand and lime. The contract was given to Messrs. Dussaud frères, who were the constructors of similar work at Marseilles, Cherbourg, and Alger. The sand as it is dredged out of the harbor is made into a concrete or mortar with the hydraulic lime from Theil, Ardeche, in France. The materials are ground together with the addition of a small quantity of sea water from time to time, and when the mixture has about the consistency of thick mortar it is rammed into box molds made of plank. In about a week the blocks so made were set sufficiently to allow the planks to be removed, and the blocks were then permitted to remain exposed to the sun and air for three months before being taken to the line of the piers and submerged. The proportions of lime and sand used were 325 kilogrammes of lime, in dry powder, to one cubic metre of sand. The dimensions of the blocks are 3^m.40 long, 2^m.00 broad, and 1^m.50 high; thus containing about ten cubic metres. A portion of the foundation of the piers was made with blocks of four cubic metres, but the casing was formed entirely of blocks of ten cubic metres, or about 370 cubic feet, and weighing about twenty-two tons. According to the calculations made in 1867, at the Exposition, the cubic contents of the piers would be 250,000 cubic metres. About thirty of these blocks were made daily in 1867, at a contract cost of 400 francs each, or about \$8 50 per cubic yard. It was estimated that 30,000 would be required.

WORKS FOR THE SUPPLY OF FRESH WATER.

One of the most interesting of the accessory undertakings necessary to the construction of the canal is the aqueduct for the supply of fresh water for the workmen and boilers, and also for the irrigation of the soil. The great work, it should be remembered, was to be executed in a desert region, where no potable water could be procured by ordinary means, and a very large supply was required for the population at Port Said, at Ismailia, and at the various encampments along the route. This supply was obtained from the Nile. A canal was dug from the end of the ancient canal at Gassassine to a point on the route of the ship canal at Ismailia, nearly half-way between the two extremes. This work was executed under the direction of Mr. Cazeau, and cost 700,000 francs. Its length is thirty miles, its width sixty-six feet, and depth six feet,

with a fall of two inches per mile. It was completed in 1861. From its termination at Ismailia the water was for some time distributed to the camps upon the backs of camels and donkeys, but a cast-iron pipe was afterward laid to Port Said and the water was forced through it by pumps a distance of fifty miles. A second pipe was afterward laid, and through these two pipes the whole line of the canal from Ismailia to Port Said is supplied.

The first pipe was six inches in diameter, and the second ten inches. Through these two pipes nearly 55,000 cubic feet of water are supplied daily.

The pumping engines are placed at Ismailia. They were constructed and placed under the direction of Mr. Lasseron. There are three steam-engines, two of fifteen horse-power each, and the third of twenty-five horse-power. The first two were erected in 1863, and the third in 1865. The two pipes connect by means of twenty joints furnished with gates. Upon the line of these pipes three great reservoirs are established, one of 500 cubic metres at El Guisr, upon the summit of the isthmus, the second, of like capacity, half-way between Ismailia and Port Said, and the third of 700 cubic metres capacity at Port Said. The pressure in the pipes reaches six atmospheres, and the highest reservoir has an elevation of only twenty metres.

SUMMARY OF THE EXTENT OF THE WORK.

At the date of the Exposition the total power of the steam-engines employed upon the isthmus was equal to 17,768 horse-power, and the monthly consumption of coal amounted to 12,219 tons. A population of 25,000 persons had been created in the midst of the desert, 13,000 of which were laborers, 6,388 of whom were Syrians, and 6,990 Europeans. The total amount of earth to be excavated, according to the plans and estimates, was 74,112,130 cubic metres, and on the first of January, 1869, less than 17,000,000 cubic metres remained to be taken out.

Among the greatest dredging works which have been executed in Europe the following are cited for comparison with the magnitude of the work upon the Suez canal.

Principal dredging works executed in Europe.

		Cubic metres.
Roadstead of Toulon.....	1848-'57, 9 years	7,400,000
Glasgow.....	1844-'65, 21 years	6,696,000
Newcastle.....	1862-'65, 3 years	6,999,000

It is also interesting to compare the extent of the work upon the piers at Port Said with similar undertakings in Europe. The length of the western jetty is about 3,100 metres, and of the eastern about 1,600 metres; the combined length being about 4,700 metres, and the total contents about 250,000 cubic metres.

The following table, for which I am indebted to the report by M. Ch. Marin upon the marine constructions represented at the Exposition,¹ shows the magnitude and cost of the principal jetties of France and England. The dimensions are stated in metres, and the cost in millions of francs. In order, however, to make a just comparison of the cost of these works, account should be taken of the differences between the bulk of the walls above and below the low-water line.

Principal marine jetties of France and England.

	Length.	Mean depth below low tide.	Total cost.	Cost per metre.	Period.
FRANCE.					
Cherbourg.....	3,750	12.00	67	18,600	1784—1853
Alger.....	1,900	18.00	30	16,000	1842—1860
Dikes and quays of Joliette.....	3,000	11.50	15	5,500	1845—1852
Dikes of the Napoleon basin.....	2,000	17.00	19	10,100	1859—1865
Fort Bayard.....	100 × 60	4.50	7		1804—1866
Fort Chavagnac, Cherbourg.....	150 × 120	10.00	5		1854—1864
ENGLAND.					
Plymouth.....	1,600	10.00	40	25,000	1817—1851
Portland.....	2,410	17.00	34	14,000	1850—1860
Holyhead.....	2,250	15.00	37	16,500	1854—1865
Aurigny.....	1,000	15.00	16	16,000	1847—1859
Jersey.....	1,050	10.00	8	7,500	1846—1856

EXTRACTS FROM THE RULES FOR THE NAVIGATION OF THE SUEZ
UNIVERSAL SHIP CANAL.

Article 1 provides that the navigation of the canal shall be opened to all vessels without distinction of nationality, provided they do not draw more than 7^m.50, equal to 24 feet 7 inches English; the canal being 8^m.00 in depth, equal to 26½ feet English.

Steam vessels will be allowed to navigate through the canal, using their own propellers; sailing vessels, above fifty tons, will have to be towed with the service established by the company.

The maximum speed for vessels in the canal is provisionally fixed at ten kilometres per hour, equal to 5.4 English knots.

The tolls for the right of transit are calculated on the measurement tonnage of the ship. This tonnage is determined for the present by the official papers on board. The toll for passage from one sea to the other is ten francs per ton measurement, and ten francs each passenger, payable on entering, either at Port Said or Suez. The charge for berthing or anchoring either at Port Said, Ismailia, or opposite the new embankment near Suez, (after a stay of twenty-four hours,) and limited to twenty days at the utmost, is five centimes per ton per day, at the place assigned by the harbor-master.

¹ Rapports du jury international, t. x, p. 316. Travaux maritimes.

